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# Experimental investigation of power generation in a microgrid hybrid network

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**Abstract :** The hybrid integration of small-scale wind and solar energy conversion systems can be used for on- and off-grid applications. This paper investigates a stand-alone off-grid application of a hybrid small-scale wind turbine and photovoltaic (PV) cell microgrid to supply houses in rural Iraq far from the utility grid. Experimental investigations were performed to measure wind speed and solar radiation, as well as the DC voltage in the rectifier section of a small-scale permanent magnet synchronous generator (PMSG) wind turbine and the DC voltage in a PV cell for 24 hours. The results showed that using a small-scale hybrid wind and solar generating system for off-grid applications in Iraq is possible if the components are equipped with proper charge controllers that perform maximum power point tracking (MPPT) during wind speed and solar radiation fluctuations.

**Keywords:** hybrid, power, small-scale, solar, wind turbine

## 1. INTRODUCTION

In off-grid rural, forest, or desert locations, dependence on conventional diesel generators presents many difficulties due to the limited availability of fuel, maintenance, and spare parts. Therefore, utilizing these generators is very expensive. The integration of renewable energy sources with diesel generators can minimize the cost and reduce the difficulties associated with using diesel generators alone. Stand-alone wind turbines and photovoltaic cells also have the ability to generate electric power without producing greenhouse gas emissions or other pollutants[1]. A wind turbine converts air flow power to mechanical and subsequently electrical power. PV cells convert solar radiation directly and statically to a DC voltage [2]. The terminals of PV cells and wind turbines can both be connected to a DC voltage bus, after which the DC voltage can be inverted by an inverter to supply an AC voltage for power applications.

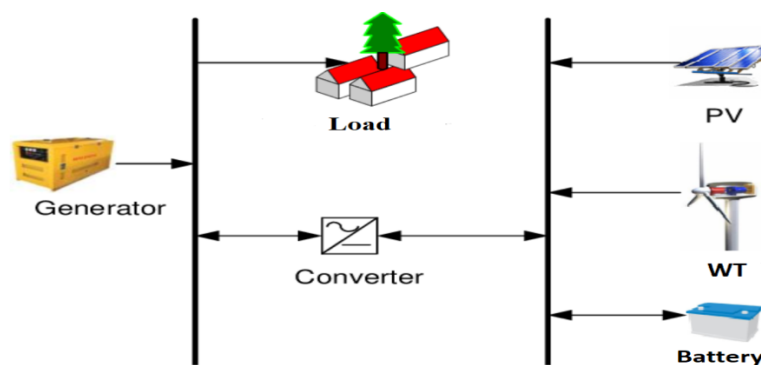
There are many studies that have investigated integrated small-scale wind turbines and PV cells for supplying power in various applications. The work presented in [3] analyzes a small-scale wind power system that uses the ventilation fan flow in livestock buildings. The properties and availability of the ventilation fan flow for utilization as the input to a wind power system for electricity generation were evaluated through field experiments and simulation. The system was tested experimentally and produced almost 300 W of electricity. In [4], an investigation is presented of a concept and realization of an electronic card that monitors and drives the power supply of a household using wind energy. The device, comprised of three blocks, enables the management and optimization of the power supply as well as the off-grid network. Knowledge in the fields of energy, electronics, and informatics

science, among others, was required for the realization and description of the system. An experimental program was designed in [5] to evaluate wind turbine generator performance in an isolated diesel-based power system. A simple model for voltage deviation was used and tested based on the installation capacity of the synchronous generator (SG) wind turbine implemented. The results were calculated using a PSCAD/EMTDC model for a grid. Another theoretical calculation and experimental investigation were undertaken in [6] for a grid-connected hybrid photovoltaic and wind energy system in which the voltage level at the DC bus was used to control the power transfer between the components of the system. The investigation was made for four grid-connected operation modes: “float, silent, sell, and low battery transfer. The researchers in [7] presented a microcontroller-based power management system (PMS), which was designed for online experimental operation of a low voltage microgrid equipped with a battery storage system and two power supplies: a kilowatt-class proton exchange membrane (PEM) fuel cell (FC) and a PV module emulator, both connected to a low voltage AC node. The main function of the PMS was to control the battery state-of-charge, which was fitted using an accurate, specially-developed algorithm. Faruk Kose et al. experimentally investigated a wind–solar hybrid system for irrigation purposes [8]. The electricity was used to power a 300 W DC-driven submersible pump 2.5 m below ground level. The amount of pumped water was calculated to sufficiently meet the water need of the crops.

In this paper, an experimental investigation is presented on the potential for electric power generation through hybrid (wind and solar) energy system integration in off-grid applications in Iraq (Near the University of Technology). This paper contains the following sections: Introduction, Materials, Test Procedures, Results and Discussion, and Conclusion.

## 2. MATERIALS

As shown in Figure 1, there are three main types of equipment used to generate DC voltage at the DC voltage bus. In this paper, analysis was performed for the operation of the generation technologies only. The load, generator, and converter are outside the scope of this analysis.” equipment is described in detail in the following sections.



**Figure 1.** Off-grid hybrid renewable energy system components and bus connections.

### 2.1. A small-scale wind turbine

A small-scale wind turbine generally contains the following components: a rotor part with numerous blades to convert the power from the wind speed to mechanical power, an electric generator, protection and control equipment, and electronic power components for feeding the produced electricity into a battery bank, DC bus, or in some cases to a direct load. [3,9]. The main component of a small-scale wind turbine is the generator. The generator converts the mechanical power into electrical power. There are two common types of electrical generators used in small-scale wind turbines: self-excited induction generators (SEIGs) and permanent magnet synchronous generators (PMSGs). The SEIG uses a gear box to match the low rotation speed of the wind turbine rotor to the high speed of the generator. In addition, the reactive power necessary to magnetize the magnetic

circuits must be fed from parallel capacitor banks at the machine terminal. The voltage or reactive power at the terminals of the SEIG cannot be directly controlled, and thus this generator may suffer from voltage instability. This research instead considered a multiple-pole PMSG, which is driven by a wind turbine rotor shaft without a gearbox [10]. The specifications of the PMSG used in this study are listed in Table 1.

**Table 1.** PMSG Wind turbine specifications.

Parameter	Value
Blade diameter	0.5 m
Start-up wind speed	4 m/s
Rated wind speed	15.5 m/s
Peak/Rated power	1100 W
Number of blades	3
Number of phases	3
Rated voltage	24 V

The power converted from the wind speed into electrical power in a wind turbine is given by the following equation [9]:

$$P = \frac{1}{2} \rho \pi R^2 C_p V^3 \quad (1)$$

where  $\rho$  represents the air density (1.225 kg/m<sup>3</sup>),  $R$  is the radius of the rotor in m,  $C_p$  is the wind generator power coefficient, and  $V$  represents the wind speed in m/s. Equation (2) calculates the power coefficient  $C_p$ , which relates to the conversion efficiency in the first stage, and is defined as the ratio between the mechanical power actually captured by the blades and the available power in the wind due to its speed [11].

$$C_p = \frac{P_{windturbine}}{P} \quad (2)$$

## 2.2. PV cell

The specifications of the single-piece PV cell PV Cell are listed in Table 2.

**Table 2.** PV cell specifications.

Parameter	Value
Peak power	300 W
Number of pieces	1
Open circuit voltage	41.6 V
Short circuit current	3.8 V
Peak power voltage	33.4 V
Peak power current	3.5 V
Rated voltage	24 V
Nominal operating cell temperature	50 °C

The power produced by the PV cell can be determined by the following Equation [8]:

$$P_{p_v} = A_{p_v} I_s \eta_{p_v} \quad (3)$$

Where  $A_{p_v}$  is the area of the PV cell in m<sup>2</sup>,  $\eta_{p_v}$  represents the PV cell efficiency, and  $I_s$  is the amount of solar radiation in W/m<sup>2</sup>.

### 2.3. Batteries

(Four Ni-Cd)12 V, 95 Ah batteries were connected in series and parallel to deliver 180 Ah at 24 V.

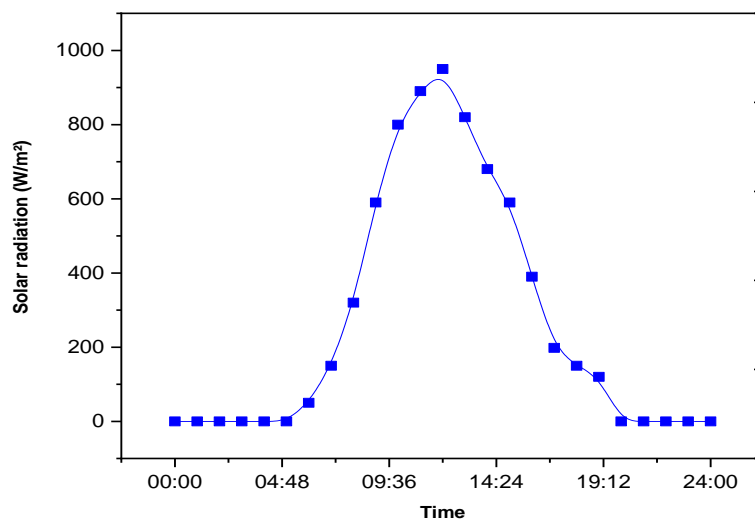
## 3. TEST PROCEDURES

Thoroughly investigating the potential applications of the hybrid renewable energy system considered in this study required implementing a variety of measurement techniques. An anemometer was used to measure the wind speed, after which we calculated the corresponding power produced by the small-scale PMSG wind turbine. The measurements were made once an hour for a 24-hour period. A voltmeter was used to measure the rectified DC voltage of the PMSG that would be fed to the DC link (DC bus).

For the PV cell, the incident solar radiation was measured using a solar meter with a variable range from 0–2000 W/m<sup>2</sup>. The device was used to measure the global total solar radiation (diffuse and beam) per unit area on the surface of the PV cell once an hour for 24 hours. To achieve maximum solar power, the solar meter and the PV cell were mounted facing south, with a tilt angle based on the location in Iraq [12].

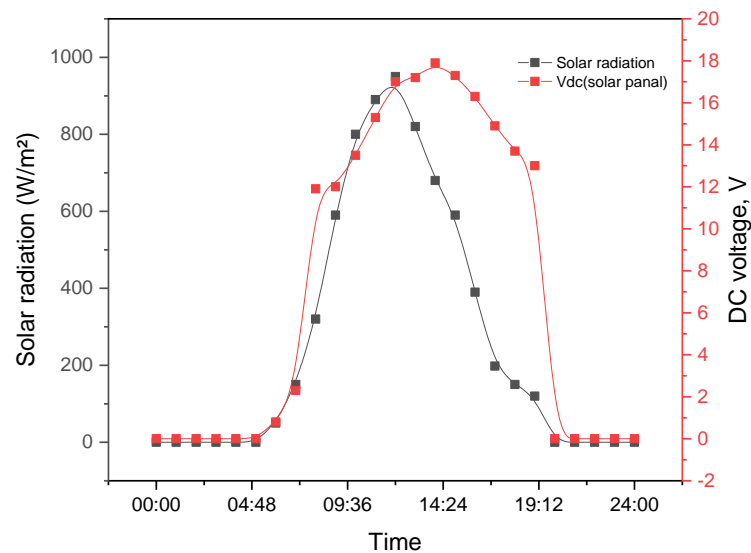
## 4. RESULTS AND DISCUSSION

The results of the solar radiation over the course of a single day are shown in Figure 2.



**Figure 2.** Measured hourly solar radiation over one day.

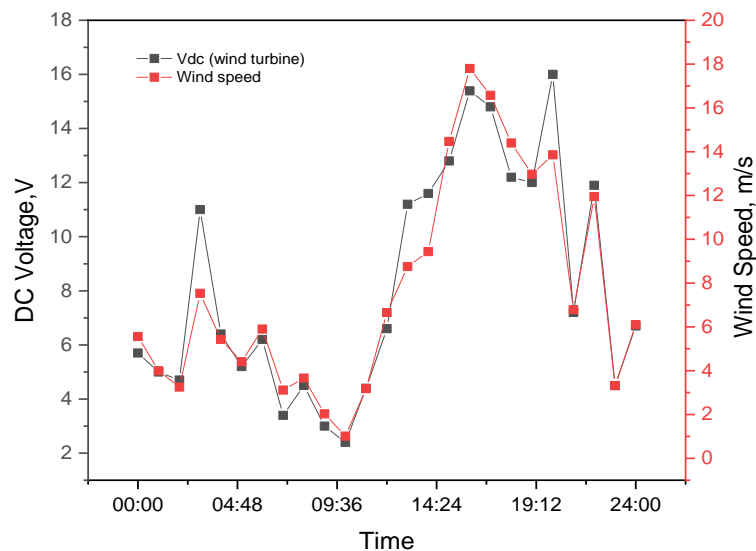
Figure 2 shows that the solar radiation increases from its lowest value in the early morning, to its maximum value at midday before decreasing gradually until sunset. The maximum solar radiation value of 920 W/m<sup>2</sup> was measured at 12:00 PM. The following day, both the solar radiation and the DC voltage (V<sub>dc</sub>) at the PV cell terminals were measured. The results are shown in Figure 3.



**Figure 3.** Measured hourly solar radiation and  $V_{dc}$  data for the PV cell over one day.

In Figure 3, the maximum solar radiation that the PV cell experiences occurred again at 12:00 PM, as seen in the results for the previous day, in Figure 2. The maximum value of the measured DC voltage, however, occurred at 2:24 PM. The maximum voltage did not occur at 12:00 PM with the peak radiation value due to the temperature decrease during the period between 12:00 PM and 2:24 PM. In the PV system, such a temperature decrease causes an increase in the efficiency of the PV panel and, correspondingly, its output voltage.

The results of the tests measuring the DC voltage of the wind turbine and the wind speed for 24 h are presented in Figure 4.



**Figure 4.** Measured hourly wind speed and  $V_{dc}$  for the small-scale wind turbine during a single day.

Figure 4 demonstrates that an increase in wind speed is accompanied by an increase in DC voltage at the wind turbine rectifier side. The maximum DC voltage value reached 16 V at 8:30 PM, when the wind speed was 14 m/s. In contrast, the maximum measured wind speed occurred at 4:50 PM, but the turbine produced a DC voltage of only 15.5 V. This means that the efficiency of the system at 8:30 PM was better than that at 4:50 PM. The efficiency of the wind turbine is affected by its temperature,

similarly to the PV cell. The discrepancies between the maximum wind speed and solar radiation and their respective maximum DC voltage outputs in figures (3) and (4) illustrate that the efficiencies of the wind turbine and PV cell operation were affected by changes in temperature throughout the day. A solar charge controller and wind turbine charge controller are therefore needed to perform maximum power point tracking (MPPT) during the daily operation of each of the wind turbines and the PV cells.

## 5. CONCLUSION

In this figure, an investigation was made of the energy generation characteristics of a wind turbine and solar PV cell for implementation in a hybrid renewable energy microgrid system for off-grid applications. The results showed that during the fluctuations of wind speed and solar power intensity, the DC voltage at the DC bus is variable. Therefore, separate charge controllers are required for each PV cell and wind turbine rectifier section to perform MPPT and achieve a constant DC voltage at the DC bus. The results also demonstrate the feasibility for implementing a hybrid renewable energy system in Iraq for off-grid applications, due to the continuous high solar radiation and wind speed.

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